XXV. *On the Variation of the Temperature of boiling Water. By Sir* George Shuckburgh, *Baronet, F. R. and A. S. and Member of the Academy of Sciences and Belles Lettres at* Lyon.

Read March 11, 1779.

THE heat of boiling water having for ſome years been uſed as one of the terms for graduating the ſcale of thermometers; together with the particular attention the Society has lately given (*vide* the Report of the Committee, Phil. Tranſ. vol. LXVII.) to this branch of inquiry, and I may add the ſingular ſucceſs with which this age and nation has introduced a mathematical preciſion, hitherto unheard of, into the conſtruction of philoſophical inſtruments, will render it unneceſſary for me to ſay more in reſpect of the following experiments, than ſimply to lay them before the Royal Society.

That the heat of boiling water was variable, according to the preſſure of the atmoſphere, ſeems to have been known to FAHRENHEIT as early as the year 1724(a).

(a) *Vide* Phil. Tranſ. N° 385. wherein is propoſed a curious project of determining the weight of the atmoſphere by means of a thermometer alone, under the title of "Barometri novi deſcriptio."

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A few years after this, Meſſieurs LE MONNIER and CASSINI (*Mem. de l'Acad. des Sc. pour* 1740) made ſome deciſive obſervations, to ſhew that this quantity was very conſiderable. It was left, however, for Mr. DE LUC to make a much more compleat ſeries of experiments, which he has deſcribed and reduced into ſyſtem in his *Recherches ſur la Variation de la Chaleur de l'Eau bouillante.* It remained only that theſe ſhould be verified. Towards the latter end of the year 1775 I had an opportunity of repeating theſe obſervations with a ſmall pocket thermometer of about ſix inches long, made by Mr. NAIRNE; an inſtrument, it muſt be confeſſed, not very accurate for ſuch an examination, but with which I thought, however, I could obſerve to within a quarter of a degree; my object at that time, amidſt a variety of other philoſophical purſuits, being to aſſure myſelf that the variation took place, rather than critically to examine the quantity of it. I ſhall relate theſe obſervations, as the reſult of them upon my return to England led me to ſome more accurate.

Table of obſervations of the boiling-point, made in a journey over the Alps.

Place of obſervation.	Height of the barometer.	Heat of boiling water by obſervat.	Heat of boiling water by Mr. DE LUC's thermometer	Diff.	Difference in $\frac{1}{100}$ of total.
	Inches.	°	°	°	
Bologna,	30.21	213.5	213.5	−0,0	0
Geneva,	28.60	210.4	210.9	−0,5	−16
Modane,	26.61	207.3	207.4	−0,1	− 2
Lannebourg,	25.75	205.1	205.9	−0,8	− 9
Mount Cenis,	24.03	201.2	202.6	−1,4	−11
Ditto,	23.91	201.1	202.4	−1,3	−10
				Mean	$\frac{9}{100} = \frac{1}{11}$

The ſecond column gives the height of the barometer at the time of obſervation; the fourth, the heat of boiling water deduced from Mr. DE LUC's rules, compared with the lowermoſt obſervation, or that under the greateſt preſſure; the ſixth gives the difference between the theory and the experiment in the motion of the boiling point in hundredth parts of the whole ſpace deſcribed: from whence it might be concluded, that the motion or variation of the boiling point with a given variation in the preſſure of the atmoſphere was $\frac{9}{100}$ or $\frac{1}{11}$ greater

greater than by the theory alluded to(b). But theſe were but groſs experiments, and perhaps unworthy of ſuch a competition. They induced me, however, to make the following. In the beginning of laſt year (1778) with the aſſiſtance of Mr. RAMSDEN, I procured a moſt excellent thermometer, every way adapted for this purpoſe. It was about fourteen inches long, but the interval between freezing and boiling only $8\frac{1}{4}$ inches(c), and though every degree was ſomething leſs than the $\frac{1}{20}$th of an inch, yet, by means of a ſemi-tranſparent piece of ivory, which applied itſelf cloſe behind the glaſs tube, ſliding up and down in a groove cut in the braſs ſcale for that purpoſe, carrying a hair-line diviſion, at the extremity of which was a vernier dividing each de-

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(b) The ſame inſtrument immerſed in ſnow juſt melting at the top of Mount Cenis fell to 32°, the point of freezing obſerved at the level of the ſea.

(c) It may poſſibly be ſuggeſted, that if this interval had been greater, *viz.* 20, 30, or 40 inches, I ſhould have had a much larger ſcale and more convenient inſtrument; but in this, as in moſt other mechanical contrivances, our progreſs beyond certain limits is prevented; for if the perpendicular height of the column of quickſilver be much increaſed, the weight of it will be ſuch as to diſtend the ball, and the inſtrument may differ from itſelf in a vertical and horizontal poſition by half a degree, as I have ſeen in a tube only fifteen inches long; and if this circumſtance be endeavoured to be corrected by making the bulb of the thermometer thicker, its ſenſibility will be proportionably diminiſhed. If my experience were to lead me to conclude any thing, I ſhould conſider a tube of a foot long as a *maximum*, and the bore of ſuch a diameter as to admit a ball of a quarter or one fifth of an inch.

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gree into ten; with, moreover, a lens of an inch focus; this apparatus being made moveable firſt by the hand, and more delicately by means of a micrometer ſcrew, whoſe head was divided into twenty-five diviſions, each equal to the fortieth of a degree (for ſo truly cylindrical was the tube, which had been with care expreſsly ſelected from a great quantity of glaſs, that the diviſions in the neighbourhood of the freezing point did not differ from thoſe near the boiling point by ſo much as $\frac{1}{40}$th of a degree, and this variation appeared in other parts of the tube ſtrictly uniform, as was found by breaking the column of mercury); by means I ſay of this apparatus I was enabled to read off any height of the thermometer to within $\frac{1}{50}$th of a degree. The veſſel, in which the water was boiled, which was always ſpring water, was a cylindrical tin pot, 13 inches high and $4\frac{1}{4}$ inches wide, with a top ſomething reſembling that deſcribed in Mr. DE LUC's work, contrived to carry off the ſteam without incommoding the obſerver, with a waſte pipe for the ſuperfluous water in boiling, which might otherwiſe fall upon the fire and extinguiſh it. The ball of the thermometer was immerſed to within $2\frac{1}{2}$ inches of the bottom of the veſſel, and $10\frac{1}{2}$ inches below the ſurface of the water, ſo that as near as might be the whole column of mercury was expoſed to the heat of boiling water,

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there being only 15° or 20° of the ſcale, equal about $\frac{1}{50.0}$ part riſing out of the water expoſed to the temperature of the ſteam, which in one or two experiments was found to be 180° or 190°, ſo that the correction for this defect of heat would only amount to a very few hundredths of a degree, perhaps about ,04 or 05, which, as the inſtrument was expoſed to the ſame circumſtances as near as might be in all the obſervations, I have taken no notice of. I thought it neceſſary to ſay thus much reſpecting the preciſion of the inſtrument and the apparatus, and ſhall now relate the obſervations at length.

Table of the obſervations.

N°	Place of obſervation.	Height of the barometer.	Therm. at.	Barometer reduced to the heat of 50°.	Boiling point.	Mean boiling point.
		Inch.	°	Inch.	° 40ths.	° 100ths
1	Summit of Snowdon in Carnarvonſhire, Aug. 15, 1778,	26,487	46	26,498	207, 8	207,07
					206,38	
2	Top of Carn Cwm Gafr, Aug. 16, 1778,	27,274	62	27,241	208,27	208,64
					208,24	
					208,28	
					208,19	
					208,29	
3	In the deſcent from ditto,	27,957	51	27,954	209,28½	209,87
					209,37	
					209,39	
					209,32	
					209,32	
					209,40	

Table of obſervations continued.

Number.	Place of Obſervations.	Height of the barometer.	Therm. at.	Barometer reduced to the heat of 50°.	Boiling point.	Mean boiling point.
		Inch.	°	Inch.	° 40ths.	° 100ths
4	Shuckburgh, Dec. 3, 1778,	28,360	44	28,377	210,17½ 210,20½ 210,20½ 210,21½	210,50
5	Ditto, Oct. 23, 1778,	28,690	47	28,699	211, 8 211,10 211,11 211,13 211,12 211,10	211,27
6	Ditto, Sept. 27, 1778,	28,910	54	28,898	211,19½ 211,20½ 211,24½ 211,17½ 211,14½	211,50
7	Ditto, Nov. 7, 1778,	18,990	47	28,999	211,23 211,24 211,25 211,23	211,60
8	Llanberis, Carnarvonſhire, Aug. 13, 1778,	29,477	60	29,447	212,22	212,55
9	London, Jan. 27, 1779,	29,790	45	29,805	212,35 212,40 212,42 212,36 212,36 212,38 212,39	212,95

Table

Table of Obſervations continued.

Number.	Place of obſervation.	Height of the barometer.	Thermo[illegible]	Barometer reduced to the heat of 50°	Boiling point.	Mean boiling point.
		Inch.	°	Inch.	° 40ths.	° 100ths
10	London, Jan. 28, 1779,	29,990	44	30,008	213, 5 213, 8 213,10 213, 9 213,18 213,10 213, 6 213, 6 213,11 213,12 213, 8	213,22
11	Ditto, June 10, 1778,	30,250	64	30,207	213,20 213,23 213,24 213,26 213,23½	213,58
12	Ditto, Dec. 27, 1778,	30,468	43	30,489	214, 5 214, 9 214, 6 214, 2 214, 5 214, 7 214, 7 214, 5	214,15
13	Ditto, Dec. 24, 1778,	30,750	46	30,763	214,18 214,12 214,15	214,37

Table

Table of obſervations continued.

Number.	Place of obſervation.	Height of the barometer.	Therm. at	Barometer reduced to the heat of 50°.	Boiling point.	Mean boiling point.
		Inch.	°	Inch.	° 40ths.	° 100ths
14	London, Dec. 25, 1778,	30,838	47	30,847	214,35 214,32 214,33 214,34 214,35 214 31 214,33	214,83
15	Ditto, at the Adelphi Wharf, 3½ feet above high water, Dec. 26, 1778,	30,948(*d*)	47	30,957	214,35 214,39 214,40 214,38½ 214 41 214,37 214,41 214,40 214,40 214,34	214,15

The numbers in the fifth column are the corrected heights of the barometer reduced to one and the ſame temperature, *viz.* 50°, which was neceſſary in order to have the true proportion of the preſſure of the atmoſphere, whoſe influence ſeems to have ſo conſiderable a

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(*d*) This is the greateſt height of the barometer that I have ever known, and, as far as I have been able to collect the higheſt point, that it has ever been ſeen to ſtand at in any country where obſervations have been made and recorded, ſince the firſt invention of this ingenious inſtrument.

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ſhare in the heat of boiling water. Column the ſixth ſhews the height the thermometer ſtood at in water boiling very faſt in degrees and 40ths of a degree; where it will be ſeen, that the obſervation was repeated, as the heat is given of every ſeparate trial, which is, perhaps, the beſt criterion of the confidence that is to be placed in the mean reſult, ſhewn in column the ſeventh expreſſed in hundredths of a degree.

Having collected this ſeries of experiments, I was anxious to ſee how far they correſponded with MR. DE LUC's, and upon compariſon of N° 1. and N° 15. I found that the decreaſe of the boiling heat was $\frac{,47}{100}$ greater than the rules admitted of from an alteration of the preſſure of the atmoſphere of $4\frac{1}{2}$ inches. This difference led me into an examination of all my obſervations, to ſee how far they were conſiſtent with themſelves; how far they diſagreed from Mr. DE LUC's; and, laſtly, what general concluſion might be drawn from them.

To avoid in ſome meaſure, or at leaſt correct, the errors of obſervation, the mean of N° 1. and N° 2. the mean of N° 0. and N° 7. and of N° 14. and N° 15. was taken inſtead of either obſervation ſeparately; the firſt and third of theſe means as two extreme terms, and the ſecond as an intermediate one: with theſe it was very eaſy by interpolation or proportion to deduce any other intermediate term, and conſequently from the mean of ſix to examine all the fifteen obſervations. Thus, on a compariſon of N° 1. and 2. with N° 14. and 15. the mean motion of the boiling point in that interval for one inch of the barometer (*viz.* when the mercury ſtands at 28,886 inches) is = 1°,743; according to Mr. DE LUC this is 1°,65. By a ſimilar compariſon of N° 1. and 2. with N° 6. and 7. the mean motion of the boiling point in that interval (*viz.* at 27,908 inches) for one inch is = 1°,779; by Mr. DE LUC = 1°,73. And, laſtly, comparing the mean of N° 6. and 7. with the mean of N° 14. and 15. the mean motion of the boiling point in this interval (*viz.* at 29,925 inches) for one inch is = 1°,709; by Mr. DE LUC = 1°,59. It ſhould follow then, that, within the limits of my experiments, the alteration or motion of the boiling point is greater (e) by $\frac{1}{18}$ than from that gentleman's obſervations, that the heat of boiling water is not directly in the ſimple ratio of the height of the barometer, nor yet is the progreſſion ſo rapid as Mr. DE LUC obſerved it. It may be ſomewhat ſatisfactory to ſee the obſervations collated and compared.

(e) It is true, that my obſervations in Savoy give this difference + $\frac{1}{11}$ thoſe of Mr. LE MONNIER equal + $\frac{1}{12}$ (Vide *Recherches ſur l'At.* § 964.); and though, perhaps, neither the one nor the other are intirely unexceptionable, they tend, however, ſomething to confirm, although alone they may be unable wholly to ſupport, ſuch a ſuppoſition.

N°

N°	Height of the baro-meter.	Boiling point by obſerva-tion.	Boiling pt. by Mr. DE LUC's rules.	Error.	Boiling point by interpola-tion from N° 1, 2, 6, 7, 14, and 15.	Error.
	Inch.	°	°	°	°	°
1	26,498	207,07	208,54	+0,47	207,18	+0,11
2	27,241	208,64	208,84	+0,20	208,52	−0,12
3	27,954	209,87	210,03	+0,16	209,80	−0, 7
4	28,377	210,50	210,81	+0,31	210,56	+0, 6
5	28,699	211,27	211,34	+0, 7	211,11	−0,16
6	28,898	211,50	211,67	+0,17	211,47	−0, 3
7	28,999	211,60	211,85	+0,25	211,64	+0, 4
8	29,447	212,55	212,74	+0,19	212,42	−0,13
9	29,805	212,95	213,15	+0,20	213,03	+0, 8
10	30,008	213,22	213,47	+0,25	213,49	+0,27
11	30,207	213,58	213,79	+0,21	213,71	+0,13
12	30,489	214,15	214,23	+0, 8	214,19	+0, 4
13	30,763	214,37	214,66	+0,29	214,65	+0,28
14	30,847	214,83	214,79	−0, 4	214,79	−0, 4
15	30,957	214,96	214,96	,0	214,96	,0

I ſhall make no deductions from this compariſon, but leave them to the leiſure of the reader. It will, however, probably be inquired, how the thermometer came to ſtand at 213° in boiling water, when the barometer was about 30 inches, 212° being the degree by which that heat is expreſſed on FAHRENHEIT's ſcale? The anſwer is eaſy: it was an error in the making of the inſtrument, and, I believe, a pretty general one. There was alſo a ſimilar error of ſomething more than one quarter of a degree in laying down the freezing point ſo that the fundamental interval between freezing and boiling, when the barometer ſtands at 29,8 inches (the mean height at London) was 180°,71 inſtead of 180°; by this means each diviſion was in fact $\frac{1}{260}$th part leſs than a degree: this ſmall correction may therefore eaſily be applied, if thought neceſſary, but I have taken no notice of it.

I will now add a general table for the uſe of artiſts in making this inſtrument, both according to my own obſervations, and thoſe of Mr. DE LUC, that the preference may be given as it ſhall be thought due; not that it is a matter of any great conſequence which is made uſe of under ſmall variations of the atmoſphere; but even under theſe circumſtances, I flatter myſelf, that the object of this paper will be ſufficiently obvious to all who wiſh to verify a new theory, or aim at accuracy in theſe days of preciſion.

Height of the barom.	Correct. of the boiling point.	Diff.	Correct. according to Mr. DE LUC.	Diff.
26,0	−7°,09		−6°,83	
		,91		,90
26,5	−6,18		−5,93	
		,91		,89
27,0	−5,27		−5,04	
		,90		,88
27,5	−4,37		−4,16	
		,89		,87
28,0	−3,48		−3,31	
		,89		,86
28,5	−2,59		−2,45	
		,87		,83
29,0	−1,72		−1,62	
		,87		,82
29,5	−0,85		−0,80	
		,85		,80
30,0	0,00		−0,00	
		,85		,79
30,5	+0,85		+0,79	
		,84		,78
31,0	+1,69		+1,57	